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Running Title: **ANAEROBIC WORK CAPACITY**

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ANAEROBIC WORK CAPACITY
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ABSTRACT

To study the anaerobic work capacity in wheelchair athletes, 67 elite wheelchair athletes (50 male and 17 female athletes) were studied in a 30s sprinttest on a computer controlled wheelchair ergometer during the World Championships and Games for the Disabled in Assen (1990).

The experimental set-up (ergometer, protocol) proved to be adequate in terms of power output (P30, P5) velocity and heart rate. Male and female athletes were comparable with respect to personal characteristics (age, body weight, training hours).

Track athletes - classified in 4 different functional classes - showed a class-related mean power output (P30: mean power produced over the 30 second sprint period) of 23, 68, 100 and 138W for the male athletes (n=38) and 38, 77 and 76W for females in the upper three classes (n=10). Sprint power was low for the group of subjects with cerebral palsy (35W; mixed, n=6) and relatively high for the amputee group (121W; mixed, n=6), female basketball players (81W, n=5) and two male field athletes (110W). Significant differences between male and female athletes were found for P30 and P5 (highest mean power output over any of the six 5 second periods).

As was to be expected, mean maximum heart rate in the sprint test varied significantly between the track groups from 112 (high lesion group) to 171b.min^{-1} (low lesion group), but not for the two sexes. The lower P30 in the T_1 and T_2 groups must be explained not only by the reduced functional muscle mass and impaired co-ordination, but also by phenomena of cardio-vascular dysfunction. Based on the performance parameters the functional classification of the track athletes into four groups seems adequate. P30 was significantly associated with the personal characteristics gender and hours of training.

A significant correlation was found between P30 and sprint performance times over 200m (r=-0.79). No correlation was found between either of the forms of power output and the marathon times.

Anaerobic wheelchair work capacity can be adequately studied with the 30s sprint test which was used in the current study. Anaerobic work capacity is highly variable among elite wheelchair athletes with different disabilities and from different sports disciplines, and appeared quite strongly influenced by functionality, hours of training and gender.

Keywords: Anaerobic work capacity, wheelchair sports, personal characteristics, training hours.

INTRODUCTION

Research on manual wheelchair propulsion has increased over the last few decades. Much of the past research predominantly focused on two areas: [1] aerobic performance capacity in wheelchair arm work (1-6) and [2] optimisation of wheelchair design and fitting (7-11). In both areas of research, power output and oxygen consumption are viewed as major indices of aerobic performance capacity, and their dependence on disability, training status and age has been fairly well documented (2-6, 12-17). Anaerobic indices of performance have not been a regular subject of research.

Obviously, anaerobic work capacity is extremely important in various sports disciplines. Moreover, many daily activities are considered to be of a short duration and are suggested to be basically anaerobic in nature (18, 19). Anaerobic work capacity of wheelchair users in general and of wheelchair athletes has been studied to a limited extent, generally on rather small and heterogeneous subject groups (4, 14, 20-24). Moreover, quite different experimental approaches are employed to study anaerobic work capacity in wheelchair confined populations (4, 21-28). As a consequence, a considerable variation in results and applications is seen, not only as a result of the high variation in work capacity among and within subject groups, but also due to variations in experimental set-up and design.

A better understanding of the upper limits in anaerobic work capacity among elite wheelchair athletes will help to set knowledge based and structured sports medical guidelines for exercise and training in wheelchair sports practice and rehabilitation. Therefore, in the current study an experimental approach was taken to study anaerobic performance among a group of experienced wheelchair athletes during the World Championships and Games for the Disabled in Assen, in The Netherlands (1990). All subjects performed two Wingate-like 30-second sprint tests (29) on a computer-controlled wheelchair ergometer in a laboratory setting. Thus, the actual limits in anaerobic wheelchair arm work could be described for a large subject group with respect to gender, functional ability and sports discipline.

The following questions were formulated:

What is the upper limit of anaerobic wheelchair work capacity (P30, P5, rate of fatigue) in elite wheelchair athletes ?

What is the relationship between personal characteristics (functional ability, gender, age, weight, number of training hours) and anaerobic work capacity ?

METHODS

Subjects

After having given written informed consent, 67 wheelchair athletes volunteered in this study. All subjects competed in the World Championships and Games for the Disabled. During the Games a functional classification system of the International Stoke Mandeville Games Federation (ISMGF) was used, based on the functional abilities of the athletes (30) to improve the quality of competition. This classification system was integrated in this study where possible. Some group characteristics of the subjects, including functional classification (for the track athletes) and the number of training hours per week (TH) are presented in Table 1., together with the resisting load during the sprint test.

INSERT TABLE 1

Test protocol

Anaerobic work capacity of the athletes was evaluated with two 30-second sprint tests in a temporary laboratory setting at the World Games. To ensure a standardised evaluation procedure for all athletes a computer-controlled wheelchair ergometer was used (31, 32). T-he ergometer allows for the momentary measurement of velocity and torque on the hand rims of left and right wheels separately. The width between the top of the rear wheels was fixed for all subjects at 0.595m. In 3 cases however, bi-trochanter width made a larger rear wheel width necessary (up to 0.69m). Seat height was individually adjusted at 70° elbow flexion with the subjects sitting upright with the hands on top-dead-centre of the hand rim (full extension = 0°). The for-aft position was set with the acromion vertically over the wheel axle. The seat angle was fixed at a 5° backwards inclination with respect to the horizontal and the backrest at 10° with respect to the vertical. The camber angle of the wheels was 4°. The wheel and hand rim diameters were fixed and 0.62 and 0.52m respectively.

Sprint test

Since the subjects were not used to the wheelchair ergometer and experimental set-up, they conducted two sprint tests, after familiarisation with the experimental set-up. The first sprinttest was considered as a try-out. The second sprint test was generally used for further analysis. Due to sampling failures however, the data of the second test could not be used in 6 cases. In those cases the first sprint test was analysed.

After a 5 minute warming-up - in which the subject practised with the ergometer - the first test was performed. In contrast to the Wingate anaerobic protocol (29) the starting velocity was set to zero (no rolling start). The resisting load of the ergometer was set to 2.5, 5, 7.5 or 10% of the total mass (expressed in Newtons) of the subject and a (virtual) wheelchair (20kg). An initial resistance was selected, based on the individual's classification , nature of the disability and gender. Actual speed was displayed on a computer monitor which was observed by the athlete and the experimenter.

After cooling down and a 10-15 min rest period the second sprint test was performed. The resistance in this test depended on the performance of the athlete in the first sprint test. If the speed in the first test exceeded values of 3 $m.s^{-1}$, the resistance was increased by 2.5 or 5% of the total mass to avoid that the velocity of the hand rims - and thus propulsion technique itself - would be the limiting factor in performance (20, 33). Verbal encouragement was provided throughout both tests. Heart rate was recorded on line with a cardiotachometer (Lectromed @, [13]). Subsequently, peak heart rate (Hrsprint) was defined as the highest heart rate during the sprint test.

Data processing

Data of the wheelchair ergometer were automatically processed with an Olivetti M24. Torque, and velocity were sampled at 65Hz throughout the sprint tests. Power output was calculated per sample for both left and right side separately from the torque applied to the hand rim (M) and the velocity of the wheel (V):

[1] $Pout = M * V * Rw^{-1}$ [W],

where Rw is the radius of the wheel (0.31m). Prior to analysis, power, torque and velocity data were low pass filtered with a cut-off frequency of 17.5Hz (2nd order recursive low-pass Butterworth filter (34)).

Power, torque, and velocity were averaged over 30s (P30, M30, V30). According to previous studies (4, 22, 29) P5 was determined as the highest mean power of the 6 successive 5s blocks. Additionally, average torque and velocity over the 5-second period (M5, V5) were determined. The rate of fatigue (RF) was defined as:

[2] $RF = (P5start - P5end) . P5start^{-1} . 100$ [%],

where P5end is the mean power during the last 5 seconds of the sprint test.

Statistics

Generally, simple descriptive statistics were used. Differences between groups were analyzed with respect to gender, and to functional ability among the track athlete groups, using a one-way analysis of variance (SPSS PC 6.0@), followed by post hoc testing when required to locate significant differences between subject groups. Since group sizes are highly variable, these results should be interpreted with care.

To establish relationships between indices of anaerobic work capacity and personal characteristics, Pearson correlation and multiple regression analysis were used for the subject group as a whole. The level of significance for all statistical procedures was $p<0.05$.

RESULTS

Subjects

Since subjects participated on a strictly voluntary basis and given the heterogeneity of the subjects in terms of functional ability and/or sports discipline, there is a large variation in group sizes. Also a remaining miscellaneous group of athletes was formed. Here the athletes were classified either by disability or sports discipline: cerebral palsy (CP), basketball players (BAS) and amputees (AMP), and those involved in athletic field events (FLD; Table 1.) .

Eventually 67 wheelchair athletes performed the sprint tests, some before, some during and others after competition in the World Championships. The track athletes (T_1 - T_4) formed the largest sports-specific group of participating athletes (n=48), who were classified in four functional classes, according to the ISMGF classification: T_1 (less capable; cervical spinal cord lesions) to T_4 (most capable; polio, lower thoracic and lumbar spinal cord lesions [30]).

More male (M: n=50) than female (F: n=17) athletes participated in the experiments. Within the track population, it was possible to identify separate male and female subject groups. BAS (n=5) consisted of female athletes only, whereas FLD (n=2) were both male (Table 1.). Although the subject group varied in terms of disability and sports discipline, the age distribution of the subjects appeared fairly consistent for the different groups. Age ranged between 16 and 46 yrs (age: 29.1±7yrs) with the majority of athletes between 20 and 30 yrs. No significant differences in age among groups were found with respect to gender and functional ability (track groups). Also, TH (n=67: 12.9 ± 6.4 hrs.wk^{-1}) was not significantly different among the subject groups. The number of training hours per week was more or less stable among the track groups, but clearly showed lower values for CP and FLD. A higher body weight was found for the male athletes ($F(1, 65)=4.2$, $p<0.05$; 62.4 versus 55.7kg).

Sprint Performance

The resisting load against which the different athletes sprinted, was significantly different between males and females ($F(1, 65)=7.82$; $p<0.05$; 49.8N versus 34.5N), and increased significantly with increasing level of functional ability, as is seen for the male track groups (T_1M-T_4M: $F(3,34) =20.5$, $p<0.01$;Table 1.). Load for T_4M was more than four times the resistance during the sprint tests of T_1M. CP performed against a low mean load, which was on average between T_1M and T_2M. The relatively high standard deviation for resisting load, especially for CP, AMP and BAS, stresses a strong intra-group variation in anaerobic work capacity (Table 1.).

INSERT TABLE 2.

Obviously, the Pearson correlation for resisting load and P30 is high (n=67: $r = 0.93$; $p< 0.01$). Table 2. contains the mean values and standard deviations of P30, P30.kg^{-1} and P5 for the different subject groups. Average absolute anaerobic capacity - P30 and P5 - for 67 athletes were 97 ± 46 W and 119 ± 57 W, respectively, with a significantly higher P30 and P5 for the male athletes ($p<0.01$), both absolute (P5: 139W versus 87W) and relative to body weight (P30.kg^{-1}: 1.77W.kg^{-1} versus 1.17W.kg^{-1}). In general, the lower work capacity for female athletes (P30: 44%, 23% and 45% in T_2, T_3 and T_4 respectively) were less apparent when considering P30 relative to body weight (19%, 11% and 36%). Due to the high body weight (97kg) of one of the subjects in the basketball group (BAS; all females) P30.kg^{-1} was relatively low for this group in comparison with the other female track groups (T_2F, T_3F and T_4F).

P30 and P5 clearly showed higher values with increasing ability, as is expressed by the ISMGF functional classification system (T_1M-T_4M, $p<0.01$). The small female T_4 group (T_4F, n=3) deviated from this pattern. The increase in P30 with functional classification for the track athletes, is composed of a stronger increase in the mean torque (M30) and a less dominant increase in mean velocity (V30; Table 2.), which is substantiated with the higher correlation of P30 with torque (M5, M30) in comparison with velocity (V5, V30; Table 3.).

Differences between groups for P5 are generally in agreement with differences found for P30. Higher P5 values compared to P30 values (Table 2.) are obviously associated with a higher mean torque in the first 5 second period (M5), since velocity (V5) appeared to be equal or slightly lower than V30 (Table 3.). P5 was 22-40% higher than the mean power output over 30 seconds (P30) and of course correlated well with P30 (n=67: $r=0.98$, $p<0.01$).

The constituents of power output - torque (M30, M5) and velocity (V30, V5) - show somewhat different patterns (Table 2.): in contrast with velocity, M30 and M5 were significantly different between males and females ($p<0.01$), whereas both velocity and torque parameters were significantly different among the male as well as the female track athlete groups ($p<0.05$; Table 2.).

Despite a clear association between sprint power output and classification of the track groups, a considerable within group variation remains. Especially in the miscellaneous groups (Table 2.), large standard deviations are seen. Extremely low values for power output were reached by two subjects with cerebral palsy (CP: 6.6 and 7.5W). These two athletes showed a negligible power output on the right hand side. On the contrary, a subject with hemiplegia in AMP achieved 99.7W with the left hand side only, which was the highest individual mean power value delivered single-sided. These intra-individual differences were expressed in the not extremely high correlation between the mean power outputs for the left and right hand side: r=0.87 ($p<0.01$).

No significant differences on gender or on functional ability among the track groups were found for RF, which varied between 25% (T_3M) and 42% (FLD) and was on average 28 ± 13% for the 67 athletes (Table 2.). Hrsprint was 158.7± 23 b.min^{-1} for the subject group as a whole. As could be expected, no gender related difference was found. As a consequence of the frequently disturbed sympathetic innervation of the heart in athletes with a spinal cord injury in the T_1 and also T_2 groups, HRsprint showed an - expected - significant increase between the male track groups (T_1M-T_4M: $F(3,34) = 20.5$, $p<0.01$).

INSERT Table 3.

Table 3. shows the Pearson correlation between parameters for anaerobic work capacity and personal parameters, as well as with the constituents of power output: velocity and torque. In contrast with P30, P30.kg^{-1} and P5, RF showed an association with M5 only. Compared to P30 relative power output P30.kg^{-1} , showed significant, but lower correlations with torque parameters. On the other hand, velocity parameters were more strongly associated with relative than with absolute power output (P30, P5; Table 3.). Torque and velocity showed significant but a limited correlation (M30/V30:r=0.57, $p<0.01$; M5/V5: r=0.58, $p<0.01$).

To verify the possible influence of some personal characteristics on anaerobic work capacity within the experimental group, age, TH and body weight were correlated with P30, both absolute and relative, P5, HRsprint and RF (Table 3.). TH - as an indicator of training status - showed asignificant correlation with all performance indices, except for Hrsprint and RF (Table 3.). A subsequent multiple regression analysis (stepwise; Table 4.) with the dependent variable P30 (absolute and relative) and P5, and with the independent variables age, weight, TH and gender, showed a significant influence of gender and TH on P30 (r^2=0.27; p<0.01). Prediction of P5 also included body weight (r^2=0.33; p<0.001).

INSERT Table 4.

Finally, a limited number of athletes participated in the 200m dash (n=20), as well as in the marathon (n=22). P30 showed a significant association with the 200m dash time (Time = -0.11*P30 + 47.9 ;r=-0.79; Figure 1.), but not with marathon time (r=-0.46; ns).

INSERT Figure 1.

DISCUSSION

In the current study a computer-controlled wheelchair ergometer (31) was used for reasons of standardisation. A previous study has shown good agreement between results of wheelchair exercise tests on a motor driven treadmill and on this ergometer (32). The second major advantage of the ergometer used in the sprint tests over the use of a treadmill is that - next to physiological measures - torque and power production can accurately be studied, also under extreme - but highly standardised - testing conditions, also allowing a detailed evaluation of propulsion technique (11, 14, 19, 20, 23, 24, 32).

Apart from differences in subjects, differences in experimental set-up and test protocols may explain part of the differences found with results on wheelchair sprint tests in literature. In contrast with the present study, Coutts & Stogryn (4), Lees (21) and Lees & Arthur (22) had the subjects use their own competitive wheelchair. It is assumed (4) that this would increase maximum power output in (some) trained subjects (those with the well fitted and technically sound wheelchairs), since the wheelchair is individually customised and subjects are highly trained with respect to their own track wheelchair and specific track propulsion technique. In the current study however, the ergometer was used, not simulating a racing wheelchair but much more a daily-use active hand rim wheelchair: the rim diameter was fixed (0.52m) and the wheelchair configuration (seat height, camber, for/aft position) was individually adjusted according to a standardised procedure. The minimal width between the top of the wheels of the wheelchair ergometer was 0.595m, which was also more than in modern racing wheelchairs. This might have been an extra disadvantage for some of our subjects. Simulation of an individual racing wheelchair for all participating athletes was however not feasible under the given conditions. Given the heterogeneous subject population, the use of highly standardised testing conditions were felt more appropriate within the scope of this study. Since differences in wheelchair quality and in the wheelchair-user interface can influence performance quite dramatically (7,9,11,13), the degree of standardisation of testing conditions and wheelchair design and fit in the current study will have excluded these influences from the experimental set-up as good as possible. Thus the differences between the various groups of athletes with varying sports discipline and functionality will be associated to differences in the 'human engine' and will not be the consequence of differences in wheelchair design or quality.

An important influencing factor on performance will be the resistance level (or the actual speed that is reached in the sprint) used in the different studies, as was previously stressed (20, 22, 33). Veeger et al (20) used a series of different load settings onto the wheels, ranging between on average 5.6 and 8.2Nm. Thus the effect of load on P30 and P5 was evaluated and proved to be highly significant, showing a decrease in power output and increase in mean velocity in the sprint- test with decreasing resistance. Moreover, Veeger et al (11) also showed that a decrease in resisting force at an equal submaximal power level (thus an increase in actual hand speed, as is seen with varying gear ratio's or mechanical advantage, which varied from 0.43 to 0.87) leads to a significant increase in heart rate and oxygen cost and to a drop in gross mechanical efficiency of hand rim propulsion from 8.2 to 6% (n=9 non-wheelchair users; Po=0.25W.kg^{-1}). Also, the effectiveness of force production dropped with increasing mean velocity. Thus people tend to become less effective at higher velocity, but constant mean power output.

To prevent this 'speed' phenomenon from limiting actual performance in the current study, the load was individualised and chosen such that mean speed on average would remain below 3m. s^{-1}. The load setting was based on functionality, training status and age of the subjects. The sequence of two consecutive sprint tests in the current study enabled adjustment of resistance to individual performance and maximum velocity in the first sprint test. Eventually load significantly increased between track groups with different functionality (T_1-T_4; Table 1.). On average the individual protocols in the current study seem to have been appropriate. Apart from the T_1M, T_1F and CP groups, speed was between 2 and 3m.s^{-1}. Especially, in the 3 mentioned groups the limited co-ordination in the upper extremities due to the disability, will be highly sensitive to high propelling speeds. In general: an increase in load (Table 1.) led to an increase in torque and power output (Table 2. and 3.), but also to an increase in the peak and mean velocity between the different groups (Table 3.), indicating that overall the chosen protocols seem to have been appropriate.

Subjects

The general scope of the current study was to describe the anaerobic work capacity - as measured during a 30s sprint test on a wheelchair ergometer - among a group of elite wheelchair athletes. Since subjects participated on a voluntary basis, a large inter-individual variation in subject characteristics was seen - both between as well as within subject groups (Table 1.). Clearly the majority of subject groups discerned in the current study is small in number thus hampering generalisation of results to a detailed level. Expected differences between male and female athletes (body weight, load) are seen. TH and age are however not significantly different between the sexes, which does improve generalisation of gender-related results. An expected trend is seen for load with respect to functional ability among the male track groups, whereas age, body weight and TH do not show any significant differences, thus improving generalisation of any ability related results for male track athletes.

Sprint Performance

Gender related differences with respect to P30 (absolute and relative) and P5, as well as the absence of any significant differences for RF and Hrsprint do support initial expectations. Results on torque (M30, M5) and velocity (V30, V5) indicate that a higher power level in male athletes is more stronger dominated by a higher force or torque production and less so by a higher velocity. Peak heart rate is age related, but in wheelchair confined individuals with a spinal cord injury, also related to lesion level. Sympathetic innervation of the heart is generally disturbed in lesions above TH6 (16) and leads on average to low peak heart rates of 120-130b.min^{-1}. The number of subjects with high lesions in the track groups is, however, low and the difference in number between the sexes does not affect the average Hrsprint for the two sexes in the current study. For the track athletes a somewhat more detailed comparison can be made. Hrsprint is indeed lower among the male T_1 and T_2 athlete groups. Although average Hrsprint is clearly lower in the T_2F in comparison with T_3F and T_4F, the considerable standard deviation and the small number of subjects in T_2F does not lead to statistically significant effects.

Despite the small number of athletes in many of the subject groups, the gross figures for anaerobic work capacity of the current study do show more or less similar ranges and trends as is found in the literature (4,14,21,22,23,33; Table 5). The trend in the results on P30 and P5 among the male track athletes are in agreement with previous studies on maximum aerobic performance in wheelchair exercise tests among subjects with tetraplegia and paraplegia (3,4 ,5,6,12,14,15), thus stressing the impact of functionality (here: lesion level) on performance.

INSERT Table 5.

Anaerobic power output (P30, P30.kg^{-1} and P5) showed higher values with increasing functional classification (T_1 to T_4) for the male athletes,. This trend and the absolute values are more or less in accordance with Coutts & Stogryn (4) and Janssen et al (14). Lees (21) studied 9 male wheelchair athletes with the conventional ISMGF classification 2-5, which is comparable to T_3M and T_4M. They found mean sprint power values of 50 to 87W, using a friction load of 1.2kg. These values are somewhat lower than in our study, possibly due to a higher velocity and lower friction load during the test. Janssen et al (14) studied 44 male spinal cord injured sedentary subjects and presented P30 values ranging from 42±26 W (n=9 subjects with quadriplegia) to 98±34 W (n=29; lower thoracic and lumbar lesions). Differences between the current study and the results of Janssen et al (14) may be due to differences in classification (a functional (this study) versus conventional classification), physical activity, disability and age. A selection of the population of Janssen et al (14) was studied in more detail by Veeger et al. (23). They studied 9 male spinal cord injured sedentary subjects (lesion level T10 to L4) in a 30s sprinttest on the same wheelchair ergometer used here. Test conditions (load 27N) were comparable to those of the current study. P30 measured 50W, ranging from 32 to 70W (right side only). This is 27% lower than the results of the T_4M group (P30 = 138W for both sides), which might be indicative of the difference between non-trained subjects versus top-athletes.

Together with P30, P5 is viewed as an indicator of anaerobic work capacity (29). Sprint power output, averaged over 5s periods (P5), was 22-40% higher than P30. From the data reported by Coutts & Stogryn (4) it can be calculated that P5 was on average 7% higher than P30 for 4 subjects with paraplegia and 17% higher for the 2 subjects with tetraplegia. The higher P5/P30 ratio in our study might be due to a difference in resisting load. A higher load may lead to an initial steeper increase in power output which is obviously reflected in P5 and thus P5/P30 ratio, as can also be derived from the data of Lees & Arthur ([22]; the ratio of P5/P30 ranged from 1.22 to 1.44 with increasing load from 1.4 to 2.4kg). Therefore, the P5/P30 ratio might be considered as an indicator of the given load. This ratio correlates with the rate of fatigue (RF: r= 0.70). The RF seems to be load-dependent as well. In Veeger et al. (20) the RF ranged from 13% to 35% with increasing friction load (0 to 22.4Nm; n=6, r=0.87). In the current study no significant differences in RF and P5/P30 ratio were established between the sexes and among the male track groups (Table 2.). This might indicate that the given resisting load was - in relative terms - equal for all groups, thus independent of functionality, leading to a more or less identical trend in the 30s sprint test.

Not surprisingly, the standard deviations in anaerobic power output are relatively large in the 'other' - cerebral palsy (CP), basketball (BAS) and amputee (AMP) groups - since several functional classes were grouped together. Unfortunately, the experimental use of current classification systems for athletes with cerebral palsy (28) or basketball players (26,27, 35) was not possible for the small numbers of subjects in these groups. Also, in the CP and the AMP group, results of males and females were averaged. The extremely high standard deviation in the CP group (Table 2.) seems to indicate a large diversity among these subjects, which may partly be due to the exercise mode (28) to which not all subjects seemed equally suited. This is also indicated in Hrsprint which on average did not reach expected peak values. In general, few data on anaerobic work capacity among subjects with CP are available (28).

Differences between the amputee group (AMP) and the track athletes are of course related to cardio-vascular problems in the spinal lesion group, but also to differences in muscular control of the trunk (and upper limbs). Essentially the cardio-vascular responses to arm work in traumatic amputees are expected not to differ from those non-disabled subjects who equally well trained in arm work. Stability of the trunk is however reduced as a consequence of the amputation, which may produce (small) balance problems and influence the technique of propulsion, especially in the double above-kee amputated subjects. In actual wheelchair propulsion the reduced weight of the amputee will reduce rolling resistance, which is an advantage in competition.

In general, basketball players may be expected to be familiar with anaerobic exercise. Overall Hrsprint, however, seems somewhat low in this subject group. This may indicate a less than optimal testing protocol for this female subject group. Comparison with studies on wheelchair basketball players are highly limited due to differences in experimental approach and the absence of female athletes in these studies (26, 27, 35).

Functionality is a difficult concept to measure in rehabilitation and sports for the disabled. In the current study it is clearly associated with classification, and it not only will be the consequence of disability, but also of training status and expertise. Training status has been simply measured through the number of training hours. Functionality in terms of classification could only be studied among the track athletes. The definition of i.e. T_1 - according to the "General and Functional Classification Guide of XIth Paralympic Games of Barcelona 1992" - for example has both a functional ("may use elbow flexors to start (back of wrists behind pushing rim), hands stay in contact with or close to the rim, with the power coming from elbow flexion, is to use the palms of the hands, pushing down on the top of the wheel in a forward direction"), neurological (C6) and anatomical connotation ("have functions of the elbow flexors or wrist dorsiflexors, have no elbow extensors or wrist palmar flexors, may have shoulder weakness" [30]). T_1 is a re-definition of class '1A, complete lesion' of the conventional classification of the ISMGF. T_2 is a re-grouping of classes '1B/1C-complete lesion-C7/8', T_3 of 'Incomplete lesion-1C/2/upper 3' and lesion level T1-T7, and T_4 stands for the 'lower 3/4/5/6' classes and lesion level T8-S2 (30).

The current study of anaerobic work capacity in a relatively large group of track athletes does seem to substantiate the value of the functional classification system for track athletes (Table 2.). Based on a cluster-analysis of track results of 904 athletes, Higgs et al (36) argue that the conventional ISMGF track classification of 8 classes may indeed be reduced to four classes only. Despite the small subject numbers in the majority of classes, the current results do seem to support this notion and the functional classification used in 1990 World Games. The majority of performance parameters differentiated between different male track classes, with the exception of rate of fatigue (RF). The complexity of this type of study is however stressed by the results of the female track groups. Too small samples to be a reliable representation of the populations of T_3F and T_4F, the results for these female athletes appear inconsistent. Important sources of variation will be the level of expertise, training status, age and detailed differences in disability.

'Training hours' seems an indicator of training status. Mean sprint power (P30), mean torque (M30), mean velocity (V30), as well as P5 showed a small but significant correlation (Table 3.) with the number of training hours. Among the track groups differences in the mean number of training hours per week are not significant. The same holds for the gender effect (Table 1.). The role of training hours on anaerobic work capacity was substantiated further in the multiple regression analysis, indicating effects of gender and training hours on P30, but not of body weight and age. As is indicated in Table 4. P5 shows an additional influence of body weight. The positive role of the frequency of sports activities on wheelchair performance capacity was previously stressed by Janssen et al (14), among a group of sedentary male subjects with spinal cord injuries.

The wheelchair sprint test enables the measurement of the anaerobic work capacity. As such it is relevant to know that the test cross-sectional results do predict performance of subjects under 'anaerobic' conditions: a 200m track race during the World Games (N=20; Figure 1.) Relative P30 correlated slightly less with 200m time ($r=-0.72$; $p<0.05$) and marathon time ($r=-0.38$, n.s.) than did P30. Lees & Arthur (22) found a correlation between P30 and 200m time which was considerably higher ($r=-0.91$) than in our study. In their experiments the imposed load was lower, leading to higher velocities, allowing the use of their own (well trained) ‘sprint technique’, while the subjects used their own - individually optimised - competitive wheelchair .

The correlation between P30 and the marathon time was not significant, which is not unexpected, since the marathon seems a considerable aerobic effort. However, other factors may have further affected the association: the subject sample in the marathon was more homogeneous than in the 200m track races (no subjects of T_1M and CP included this subsample). Next to the homogeneity of the population sample, the technical state and ergonomics of the wheelchair may to play a more dominant role in the marathon than in a short distance race, whereas tactical aspects of the event are more important, which consecutively may influence final track times. In conclusion, methodological problems may strongly influence the correlation between wheelchair test performance and actual track performance.

CONCLUSIONS

The static wheelchair ergometer allows the analysis of wheelchair sprint performance and thus anaerobic work capacity under standardised conditions and enables a more detailed analysis of the effects of functionality (disability, classification, training status) upon performance. Results on wheelchair athletes are indicative for the maximum performance level of wheelchair arm work in the different subgroups of the user population in general. Thus it will help to set specific goals for rehabilitation programmes and sports training of wheelchair dependent individuals.

Anaerobic work capacity is highly dependent upon gender and the functionality of the population. P30 and P5 vary widely between track groups - arranged according the ISMGF classification for track athletes. Evaluating performance capacity of (individual) wheelchair athletes or wheelchair users in general should therefore take place within the methodological framework of the test procedures and within the framework of the functional capacity of the specific population. In the current study among wheelchair athletes, an important indicator of performance other than gender and body weight, seems the number of training hours, a factor which can be influenced quite easily. One should bare in mind, however, that the current study is cross-sectional. Causal relations between i.e. hours of training and performance can be derived from a longitudinal design only.

Sprint power output as measured with the described protocol may seem an indicator for short distance track performance (200m), although one must be clearly aware of the methodological problems comparing test and track results in general. Future studies must determine the true predictive value of standardised indicators of work capacity and sports performance.

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Table 1.

N	Gender	Class	Disability	Age [yrs]	Weight [kg]	TH [hrs.wk^{-1}]	Load [N]
N=67 F(1,66)	-	-	-	29.1±7	60.7±12*	12.9±6	45.9±18**
N=50				29.5±7	62.4±11	13.5±7	49.8±17
N=17				27.9±5	55.7±14	11.1±5	34.1±16
TRACK							
3	M	T_1M^*	C5-C7$	30.7±8.3	61.7±7.6	11.3±1.2	14.3±1.2
4	M	T_2M	C6-C7	29.5±7.2	66.0±9.3	15.8±7.2	35.6±4.0
8	M	T_3M	T3-L1	31.4±2.8	62.1±8.8	13.5±3.0	54.0±7.2
23	M	T_4M	T6-S1,POL,SB	27.0±5.4	59.9±11.8	15.9±7.3	58.4±10.7
F(3,34)				-	-	-	b
4	F	T_2F	C5-C7,POL	29.0±2.9	46.0±4.1	13.4±3.3	21.2±3.5
3	F	T_3F	T8,SB	26.0±5.6	52.3±10.1	13.8±6.8	37.9±8.1
3	F	T_4F	T12-S1,SB,POL	23.0±3.5	51.3±8.1	12.5±2.5	36.4±7.2
F(2,7)				-	-	-	a
MISCELANEOUS							
6	1F/5M	CP	CP	28.7±11.4	62.3±10.3	5.7±3.3	25.0±17.9
6	1F/5M	AMP	A1,A2,KA,HEM	30.8±9.3	66.2±13.0	13.2±5.8	55.2±17.7
5	F	BAS	A2,C6-7,POL	30.8±6.3	67.6±18.4	8.4±5.5	44.5±22.1
2	M	FLD	T10-L5	46.0	68.5	3.5	53.4

[*]T_1M: ISMGF functional classification T_1 ,male (M) subjects; CP: cerebral palsy ; AMP: amputees; BAS: basketball players; FLD: field athletics.

***,**,-: significantly different between male (n=50) and female (n=17) athletes: respectively p<0.05, p<0.01, not significant.**

a,b,-: **significantly different among male or female track groups: respectively p<0.05, p<0.01, not significant.**

Table 2.

N		P30 [W]	P30.kg^{-1} [W.kg^{-1}]	P5 W]	V30 [m.s^{-1}]	V5 [m.s^{-1}]	M30 [N.m]	M5 [N.m]	RF [%]	Hrsprint [b.min^{-1}]
N=67		97±46**	1.61±0.77*	119±56**	2.2±0.5	2.2±0.5	14±5**	18±7**	28±13	159±23
M:n=50		108±45	1.76±0.79	132±56	2.2±0.5	2.2±0.5	15±5	19±6	28±15	159±23
F: n=17		66± 32	1.17±0.45	81±39	2.0±0.5	2.0±0.5	10±5	16±7	29±10	158±25
TRACK										
T_1M	n=3	23±4	0.36±0.04	27±8	1.5±0.2	1.3±0.1	5±1	8±4	32±18	112±8
T_2M	n=4	68±9	1.03±0.08	89±13	2.1±0.1	2.0±0.2	11±1	16±4	33±9	126±24
T_3M	n=8	100±16	1.65±0.39	118±19	2.1±0.4	2.2±0.3	15±2	19±4	25±11	162±16
T_4M	n=23	138±24	2.36±0.46	170±34	2.6±0.3	2.6±0.3	17±3	23±5	35±12	171±12
F(3,34)		b	b	b	b	b	b	b	-	b
T_2F	n=4	38±10	0.83±0.19	46±12	1.8±0.3	1.6±0.2	7±1	11±2	41±2	134±34
T_3F	n=3	77±17	1.47±0.10	89±18	2.3±0.1	2.1±0.3	11±2	15±3	24±2	162±11
T_4F	n=3	76±5	1.51±0.21	95±10	2.4±0.3	2.2±0.1	11±2	15±2	31±7	179±17
F(2,7)		b	b	a	a	a	a	a	a	-
MISCELANEOUS										
CP	n=6	35±36	0.51±0.48	47±48	1.6.4	1.2±0.6	8±5	11±10	34±12	149±24
AMP	n=6	121±3 5	1.85±0.43	148±44	2.5±0.3	2.3±0.4	17±6	19±4	27±8	166±15
BAS	n=5	81±40	1.16±0.37	104±47	2.2±0.2	1.8±0.2	13±6	22±8	41±3	158±17
FLD	n=2	110	1.62	141	2.3	2.4	16	19	42	163

NOTE: All parameters, except heartrate (Hrsprint) are based on summed values for left and right hand side

[*]T_1M: ISMGF functional classification T_1 ,male (M) subjects; CP: cerebral palsy ; AMP: amputees; BAS: basketball players; FLD: field athletics.

***,**,-: significantly different between male (n=50) and female (n=17) athletes: respectively p<0.05, p<0.01, not significant.**

a,b,-: **significantly different among male or female track groups: respectively p<0.05, p<0.01, not significant.**

Table 3.

	LOAD	**P30**	**P30.kg^{-1}**	**P5**	**Hrsprint**	**RF**
AGE	0.10	0.04	-0.16	0.07	-0.15	0.25*
WEIGHT	0.41**	0.31*	-0.12	0.36*	0.09	0.20
TH	0.34**	0.41*	0.39**	0.44**	0.14	0.14
M30	0.99**	0.94**	0.77**	0.93**	0.50**	0.11
M5	0.87**	0.84**	0.66**	0.87**	0.49**	0.33**
V30	0.53**	0.70**	0.80**	0.71**	0.49**	0.23
V5	0.56**	0.73**	0.81**	0.72**	0.50**	0.23

n=67; Two-tailed Pearson correlation; *:$p<0.05$; **:$p<0.01$

Table 4. Results of multiple regression analysis

Dependent variables	Independent variables (+intercepts)	SE	P	Adjusted R^2
P30	2.64 TH	0.76	0.000	0.17
	-35.6 gender	11.1	0.009	0.27
	107.5 constant	18.9	0.000	
P30.kg^{-1}	0.04 TH	0.013	0.002	0.14
	-0.60 gender	0.14	0.003	0.21
	(-0.015 body weight	0.007	0.04	0.25)
	2.75 constant	0.58	0.000	
P5	3.4 TH	0.93	0.000	0.18
	-0.35.3 gender	14.0	0.014	0.28
	1.29 body weight	0.51	0.015	0.33
	(constant)		ns	

Table 5.
Review of wheelchair sprint results in relation to subject groups (WCD:wheelchair dependent; AB: able-bodied) and measurement time for a number of studies and the current result.

	Subjects	Time (s)	P30(W) (sd)	P_5(W) (sd)	RF(%) (sd)
Current Study	67 WCD	30	97(46)[@]	119(57)	28(13)
Lees/Arthur (22)	6 WCD	30	102-149[#]	-	-
Lees (21)	9 WCD	30	68(1)	109[*]	-
Coutts (4)	6 WD	30	92(51)	101	-
Janssen et al (14)	44 WCD	30	84(40)	-	-
Woude et al (33)[&]	5 AB	17	191(37)	214(36)	13-35
Veeger (23)					
uni-lateral	9 WCD	30	50(15)	58(16)	-
uni-lateral	10 AB	30	48(4)	56(4)	-

[&]: twice the uni-lateral power values
[@]: mean (standard deviation)
[#]: values in dependence of different workloads
[*]: defined as peak power, however interpreted by the authors as being close to P_5.